Tools for exploring habitat suitability for steppe birds under land use change scenarios

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ABSTRACT

In this study, scenario development based on changes in key socioeconomic drivers (namely, the prices of conventional food products, rural development policies and agro-environmental regulations) was used together with resource-based habitat suitability models to develop plausible visions of future pathways of agricultural land use and evaluate their potential consequences on conservation of target species. Analyses focused on three steppe bird species in a protected Natura 2000 area, located in the Iberian Peninsula. Our results showed that changes in land use composition under different scenarios can have important effects on habitat suitability, but that the size of those effects would vary depending on species-specific requirements and spatial distribution of land use changes. Positive effects of some new crops in the study area (grain legumes and aromatic plants) on studied species were suggested by our analyses. A positive effect of aggregation of land use changes was also found for two of the studied species. Scenario building and forecasting using transferable inter-disciplinary knowledge can therefore improve our capability to anticipate future changes and provide timely advice towards long-term conservation planning in agricultural systems.

Keywords: conservation policy; farming systems; habitat suitability; land sharing; resource availability

1. Introduction

Human activities cause multiple changes to ecosystems properties and functions resulting in important impacts on biodiversity and the associated services they provide (Pimm et al., 1995). In response to such changes, large-scale conservation efforts have been deployed to develop policies and management strategies to halt and reverse current biodiversity trends. The cornerstone of conservation policy instruments is the designation and management of protected areas with strict regulations of human activities (Margules et al., 2000). However, in many cases, restricted area protection is not enough to preserve biodiversity because their conservation depends on human managed lands, such as agricultural landscapes (Benton et al., 2003; Donald et al., 2001). It is unlikely that enough protected areas will ever be designated in these kinds of systems due to economic, social and political limitations (Henle et al., 2008).

Human activities and interests are mainly determined by socio-economic factors that are highly dynamic and often difficult to predict (Ewert et al., 2005). Conventional conservation strategies have not always taken into account the underlying dynamism of socioeconomic drivers and its potential consequences on biodiversity and management before changes occur (Sutherland and Woodroof, 2009). Rather, conventional conservation approaches have usually been problem-solving oriented and focused on reducing current conservation threats by building conservation strategies based on previous empirical experience and current socioeconomic conditions (Fischer et al., 2012). While this approach may be valuable in some cases, moving towards approximations that look more into the future, scanning potential socioeconomic developments and projecting their implications on biodiversity, may improve our capability to anticipate future changes and provide timely advice towards long-term conservation planning (Peterson et al., 2003; Sutherland and Woodroof, 2009).

Scenario development offers a methodology for thinking about possible complex situations that can occur in the near future (with more or less uncertainty) and their potential environmental consequences (Peterson et al., 2003; Lindborg et al., 2010; Mouysset et al., 2012).. By allowing the comparison about potential future developments, scenarios can help to take actions to support the best options in the future, optimize strategies, for example by focusing on conservation efforts that are more likely to be successful under most scenarios, or be prepared to quickly adapt to unfavorable environments. However, when adopted, land use change scenarios have usually been based on land use trajectories derived simply from observed trends in land uses (e.g., Brotons et al., 2004; Seoane et al., 2006). Such approach appears limited, as land use changes are often largely determined by socioeconomic drivers with future variability not experimented yet, such as prices of food products, rural development policies or agri-environmental regulations (Westhoek et al., 2006; Bolliger et al., 2007), so a vast range of potential land use developments may exist (Mouysset et al., 2012; Princé et al., 2013).

Throughout Europe, agricultural intensification over last decades has led to biodiversity losses and population decline of several species associated with farmland habitats (Benton et al., 2003; Donald et al., 2001). Of particular concern has been the decline of steppe bird populations in the Iberian Peninsula, which is part of the western European stronghold of many of these species (Bota et al., 2005). Most conservation emphasis in these areas has so far been centered on avoiding negative effects of agriculture intensification on these species, usually based on paying farmers to maintain extensive practices (e.g. improvement and conservation of field margins, provision of fallow land or a delay of the cereal harvest date) through agro-environmental schemes (e.g., Brotons et al., 2004; Lapiedra et al., 2011). However, different land use developments may occur (Ewert et al., 2005; Westhoek et al., 2006), which stresses the necessity to be prepared for possible novel changes. As with other ecosystems, major uncertainties affecting the direction of future development in semi-arid farmland habitats relate to the societal role of economic objectives versus sustainability, equity and environment; and the emphasis on globalization versus regionalization in the future.

In this study, scenario development based on changes in these important socioeconomic drivers was used to develop plausible visions of future pathways of agricultural land use within a protected Natura 2000 area, located in the northeastern part of the Iberian Peninsula. Additionally, its potential consequences on habitat suitability for steppe bird species were evaluated. Analyses focused on three steppe bird species with high-conservation value at the European level (Annex I Directive 2009/147/EC), which still have important local populations in the study area (Estrada et al., 2004). Study species included the little bustard *Tetrax tetrax*, stone curlew *Burhinus oedicnemus* and calandra lark *Melanocorypha calandra.* These species have been considered as representative of steppe-like habitats in previous studies (Brotons et al., 2004; Bota et al., 2005), although variation in responses to vegetation structure and diet may affect species-specific habitat suitability at small spatial scales (Cardador et al., 2014a; Concepción and Díaz, 2011).

Our general aim is to highlight how scenario building and forecasting can help conservation planning. Our framework comprised three steps. First, the description of scenarios of agricultural land use change based on socio-economic considerations and the local agronomic potential. Second, the stochastic allocation of land use changes associated with each scenario to spatial units, taking into account environmental (agronomical) constraints as well as different levels of spatial aggregation. Finally, the translation of agronomic scenarios into species-specific habitats by means of resource-based habitat suitability models previously developed and validated in the study area (Cardador et al., 2014a). The validity of our approach for conservation planning is discussed.

2. Methods

The agricultural land use scenarios were developed for an agricultural area with high conservation value for steppe bird species, located in the Catalan part of the Ebro basin (north-eastern Spain, 41º 35´ N, 1º 00´ W). It comprises around 65 km^2 of farmlands, included in a Special Protection Area of the Natura 2000 network, a key policy instrument for continental wide biodiversity protection in Europe. The landscape is predominantly flat and low altitude and has a semiarid Mediterranean continental climate. Currently, the area is mainly occupied by rainfed agriculture in which winter cereals (barley and wheat) are the predominant crops with almost 70% of the surface, followed by typical Mediterranean tree crops such as almonds and olives (Table 1). Fallowing is residual in the area, as well as irrigated tree orchard plantations (Cantero-Martínez and Moncunill, 2012).

2.1. Scenario building

Scenario development for the study area was based on the three main drivers that were known to primarily influence the direction of land use decisions, namely (1) the prices of food products, (2) rural development policies and (3) agro-environmental regulations (Bolliger et al., 2007; Ewert et al., 2005). We made qualitative assumptions about how these drivers might vary over the next decade under different storylines partially inspired on previous available works [i.e., the emission scenarios of the Intergovernmental Panel on Climate Change (IPCC SRES, 2000), ATEAM scenarios (PIK, 2004), the EURURALIS scenarios (Westhoek et al., 2006) and the UK National Ecosystem Assessment (UK NEA, 2011)]. Storylines were structured along two major axes that represent the main uncertainties of future development in our study area: (1) the societal role of economic objectives *versus* sustainability, equity and environment and (2) the emphasis on globalization *versus* regionalization (Fig. 1).

Changes in these main socioeconomic drivers were then translated into potential changes in local land use composition based on authors' expert knowledge (Table 1). These took into account the environmental constraints imposed by a semiarid Mediterranean climate (i.e. high temperatures and water availability limitation for crop growth) as well as farming traditions that influence land use decisions (Alvaro-Fuentes et al., 2009; Cantero-Martínez and Moncunill, 2012; Cantero-Martínez et al., 2007). Cereal crops, orchards (i.e., olive trees and almond trees) and vineyards were expected to be the dominant cover types under all scenarios considered. However, the relative percentages of such crops and the probability of occurrence of others such as fodder (mainly vetch, alfalfa and winter cereals for forage, such as oats and triticale), oil seed crops, grain legumes (mainly peas, chickpeas and beans) or aromatic plants (e.g., lavender, mint, chamomile) were expected to vary according to changing socioeconomic drivers. In addition, the study area is currently subject to an irrigation scheme development (canal Segarra-Garrigues project) that may allow the irrigation of this area (Brotons et al., 2004; Cantero-Martínez and Moncunill, 2012). Thus, two sub-scenarios for each storyline considered were built: one under rainfed conditions, and one that included partial irrigation (Fig. 1, and Table 1). The irrigation transformation will allow either a full (i.e., 6,500m^3/ha) or a partial (i.e., 1,500-3,500m^3/ha) irrigation strategy; however, partial irrigation was believed to be more realistic for our scenarios. All scenarios were developed by a collaborative working group (composed by the authors) that included conservation biologists, socio-economists and agronomists. Storylines and final values for land use specific surface demands for the whole area were developed collectively in two day-workshops and agreed by consensus.

The *"Business as usual"* scenario assumes the continuation of current trends in main socioeconomic drivers. All forms of trade policies for agricultural products will be maintained without new reductions in market access and domestic support. The existing European Common Agricultural Policy (CAP), with its two different pillars (for rural development and environment) will also be maintained. However, ecological direct payments for conservation contracts are likely to be reduced because governments will be forced to revise expenditures in the current context of economic crisis (Ringland, 2010). The business as usual scenario will not significantly change the land use composition within our study area, except for fallow land surface, which is expected to disappear following reduction in direct conservation payments (Table 1). Winter cereal fields will continue being the dominant crop type. Besides, following the tendency of last decades towards the production of more high-priced products, an increase of orchards, particularly olive trees and vineyard is expected. Furthermore, following increased societal and state support to environmental improvement, an increase in oil seed crops for biofuel production is expected, with relatively higher proportion if partial irrigation is present (increased profitability).

The *"Liberalization"* scenario implies that the current context of moving towards more open markets at the international level will be strengthened. Economic objectives will primarily drive socioeconomic development and no public support will be given neither to rural development nor conservation. The environmental legislation, as developed in EU (i.e. Nitrates Directive, Water Framework Directive, Bird and Habitat Directives, National Emissions Ceiling Directive, pesticide policy, etc.) will partly be withdrawn or modified in order to keep the agriculture sector competitive in the world market; and complete land use freedom will be implemented. In the absence of irrigation, the search of higher profitability is expected to lead to cereal monocropping to maximize yields in the study area, since cereal crops such as barley are well adapted to water-limited agro-environments. However, if partial irrigation is present, a reduction of cereal fields towards higher-priced crops such as orchards, fodder and oil seed crops is expected (Table 1).

Under the *"Development of local markets"* scenario, state and society will be interested in managing resources for the future and will make a conscious effort to reduce the intensity of economic activity. People will be motivated to live in low carbon economies, and consequently depend more on local resources for food. Demand for more expensive organic or other label products is likely to be higher than today and a strong rural development policy is expected. In the study area, promotion of crops potentially subject to local quality labels will lead to an increase in olive and almond trees, vineyards and aromatic plants (the latter, only if partial irrigation is present). Agricultural diversification with the inclusion of low proportions of other crops such as grain legumes and oils seed crops, is also expected (Table 1).

Scenario maps with the locations of the expected land use changes were generated by spatial allocation of the scenario-specific demands. Current field units in the study area were considered as starting point. Although land uses were allocated randomly, the set of allowed spatial configurations were restricted using spatial information on variables that act as physical constraints for the different land uses. Specifically, cereals, grain legumes, oil seed crops and fodder, were not allowed in field units smaller than 0.5 ha with slopes higher than 8º (limited access to commercial machinery); and fruit trees were not allowed in medium to high saline areas (salinity data elaborated in 1997 by the entity REGSEGA-INARSA). Constraints relative to the conversion of land use from one crop type to another were considered to be negligible compared to those imposed by socioeconomic drivers and physical land characteristics. For each scenario, the land uses of initial map of field units were updated as follows. First a land use was selected at random using a multinomial distribution with probabilities following the land use demands that remained to be spatially allocated. Then, a field unit was selected at random from the pool of field units where the selected land use was allowed according to environmental constraints. This operation was repeated iteratively until the scenario-dependent surface frequency per land use category was reached. The newly generated land use of a given field unit was not allowed any further transformation.

To measure the importance of spatial aggregation of land use changes on habitat suitability, two different levels (low *vs* high) of spatial aggregation of land use changes were induced (Fig. 1) by introducing a term modifying the probability of choosing field units near those that were allocated the same target land use in previous iterations (see Appendix A for a more detailed explanation, see also Fig. A1 and A2 for examples of mapped distributions). For each scenario, 10 replicates were generated in order to control for uncertainty in land use spatial distribution.

2.2. Resource-based habitat suitability estimates

Resource-based habitat suitability estimates were calculated for little bustard, stone curlew and calandra lark. To estimate the overall habitat suitability of a given field unit for a given species and thus, species occurrence probability, we proceeded as follows. A resource-based modeling approach (Cardador et al., 2014a) to estimate nesting and foraging habitat suitability for each species in a given land use was used. Under this approach, habitat suitability is defined in a broad sense as the degree of coincidence between species resource requirements (i.e., vegetation height for nesting, and food resources and vegetation height for foraging) and resource availability in that land use (see Appendix B, for more detailed explanation). Factors affecting steppe bird habitat requirements should be adjusted at the spatial scale of habitat use of the species, i.e., their home ranges (Cardador et al., 2011; Van Dyck, 2012), which may influence the species perception of landscape (Concepción and Díaz, 2011; Suárez-Seoane et al., 2002). Thus, focal statistics were used to adjust the nesting and foraging suitability values of a given field unit depending on the suitability values of the land uses around this field unit, in a radius-area representative of the focal species' home range (Cardador et al., 2014b). This radius was estimated as 250 m for calandra lark (Morgado et al., 2010; Sanza et al., 2012) and 500 m for both little bustard (Lapiedra et al., 2011) and stone curlew (Caccamo et al., 2011;

Green et al., 2000). Then, since both nesting and foraging habitat suitability are essential to ensure population viability (Catry et al., 2013), final habitat suitability in each field unit of the study area was calculated as the geometric mean between focal foraging and nesting habitat suitability values (Cardador et al., 2014a). For scenario comparison, an estimate of complete habitat suitability for the whole study area was then calculated as a weighted average of habitat suitability across all field units. Finally, the estimated surface of suitable habitat in each scenario was calculated, by transforming habitat suitability outputs into suitable/unsuitable habitat using the threshold value that maximizes the sum of sensitivity plus specificity using real data (see below). This was done to analyse whether changes in the suitability index can be interpreted only as changes of habitat quality or net loss/increase of surface of suitable habitat.

Resource-based habitat suitability predictions were validated by comparing predicted values at the field level to observed species´ occurrence data in the study area. These comparisons relied on three indices: AUC (Area Under the Receiver Operating Characteristic Curve) as a threshold independent measure of model performance, sensitivity (i.e., proportion of correctly predicted presences) and specificity (i.e., proportion of correctly predicted absences). For sensitivity and specificity analyses, the value of presence probability that maximized the sum of sensitivity plus specificity was used as a threshold to transform our model predictions to presence/absence data (Liu et al., 2005). Observed presences and absences for validation were available for stone curlew and calandra lark from standardized censuses conducted using the method published in Zozaya et al. (2010) in the study area in 2010 and 2011. For little bustard presence data consisted of observations of females with broods, obtained by standardized surveys throughout the study area by car (Tarjuelo et al., 2013) during the breeding period of 2011. For this species, an equal number of randomly generated pseudo-absences from areas where little bustard is not known to reside in the study area were thus used for analyses. AUC was calculated using the functions 'somers2' from the 'Hmisc' library in R software, taking the final value of complete habitat suitability in each parcel as the predicted data, and presence/absence or pseudo-absence data (see above) as observed values. Sensitivity and specificity were calculated using the function 'accuracy' from 'SDMTools' library.

3. Results

Estimated foraging and nesting habitat suitability based on the resource-based models varied markedly both between land uses and species (Table 2). Overall, the highest foraging and nesting habitat suitability estimates were calculated for fallow systems and grain legumes for all species considered, with suitability values ranging from 0.29 to 1. Orchard crops also offered high foraging habitat suitability for stone curlew (0.50-0.79) and cereal and fodder crops offered high nesting suitability for little bustard (0.61-0.63). When spatially implemented to the study area, taking into account the scale of habitat use of the species (see above in section 2.2), the agreement between predicted and observed occurrence data was reasonable for the three species considered. AUC values were 0.66 for calandra lark, 0.77 for little bustard and 0.70 for stone curlew (Table 3). According to our resource-based models, current percentage of suitable habitat in the study area varied among species, ranging from 39 to 57% at present time (Fig. 2).

3.1. Suitability projections under alternative scenarios

For the three study species, expected changes on average habitat suitability estimates in the whole study area strongly differed between scenarios considered and the level of spatial aggregation of land use changes (Figs. 2, A1 and A2). Differences in average habitat suitability estimates matched differences in predicted percentage of suitable habitat (Fig. 1). Most scenarios considered were expected to lead to reductions in average surface of suitable habitat for little bustard and calandra lark in the study area (between 20 and 100% of reduction for little bustard and between 7 and 100% for calandra lark according to averaged values across replicates). This is because most of them will lead to the promotion of farming systems with low or null habitat suitability for these species such as vineyards and orchards (olive and almond trees), and the loss of more suitable open-land crops such as cereals, fodder and fallow land (Table 1). For both species these reductions were expected to be lower if changes in land uses were aggregated, and thus the probability of having contiguous suitable habitat at the scale of home-ranges higher (13-92% lower than averaged reductions predicted according to non-aggregated scenarios for calandra lark, except for the "business as usual" scenario with partial irrigation, and 16-77% lower for little bustard, except for the "business as usual" scenario under rainfed conditions, Fig.2). By contrast, for the stone curlew, higher suitability indices for most scenarios were predicted when land use changes were non-aggregated (Fig. 2).

The "business as usual" scenario and the "liberalization" scenario under rainfed conditions lied within the scenarios with higher predicted habitat suitability for little bustard and calandra lark, particularly with aggregated changes (36-42% and 30-36% of suitable habitat for each species, respectively, according to averaged values across runs), and predicted similar habitat suitability as at current time for stone curlew (62-63%, Fig. 2). This latter species was predicted to benefit from most of the other scenarios considered (Figs. 2, A1 and A2), due to an increased presence of orchard crops, which had high resource provision for this species (Table 1). By contrast, the "business as usual" scenario with partial irrigation was one of the scenarios with overall low habitat suitability values for all species (Fig. 2).

4. Discussion

Our assessments of potential effects of changes in agricultural landscape composition on steppe birds relied on species resource-based suitability models, allowing the transformation of structural land cover types into functional habitat types, based on the expected provision of necessary resources for foraging and nesting for the considered species (Cardador et al., 2014a; Butler and Norris, 2013). Habitat suitability estimates generated by our models were congruent with independent contemporary species' occurrence data in our study area. According to such estimates, our results showed that changes in land use composition under different scenarios can have important effects on habitat suitability, but that the size of those effects would vary depending on species-specific requirements and spatial distribution of land use changes (Suárez-Seoane et al., 2002; Fahrig et al., 2011).

Globally speaking, most of the scenarios considered are expected to lead to increases in orchard crops in the study area, which are high-priced and value-added products compared to cereal crops. These changes in landscape structure will likely affect the conservation of ground-nesting open-land farmland species (Guerrero et al., 2012). Accordingly, our models predicted reduced suitability values for calandra lark and little bustard in the study area under such land use change scenarios, but also indicated that the third considered species, stone curlew, might benefit from such changes. The same occurs regarding the effect of partial irrigation compared to rainfed scenarios: stone curlew globally seems to perform equally or better with irrigation, contrary to calandra lark and little bustard, which appear to be more sensitive to its consequences (Brotons et al., 2004). In this respect, our results provide evidence that some crops with low current presence in the study area, such as grain legumes or aromatic plants, which might be promoted under some of the scenarios considered, have the potential to host similar or even higher suitability values than more traditional crops such as olive and almond trees or cereal crops for considered species, particularly for calandra lark and little bustard.

Interestingly, the effect of agricultural composition on studied species is highly influenced by the level of spatial aggregation of land use changes. For both calandra lark and little bustard, the predicted reductions in habitat suitability were lower if changes in land uses were locally aggregated, probably because it increases the probabilities of finding continuous suitable habitats at lower spatial scales (Morgado et al., 2010; Reino et al., 2010), thus reducing energy expenditures to fill ecological requirements. The different results obtained for stone curlew may be related to its more generalist behavior (Green et al., 2000), potentially allowing this species to find continuous (and more diverse) suitable habitat even if land use changes are not aggregated. The relative importance of configurational heterogeneity (i.e., the spatial arrangement of cover types) has recently gained notoriety in conservation (Brotons et al., 2005; Fahrig et al., 2011; Giralt et al., 2008). There is a growing interest in the concept of land sharing for conservation, i.e., integrating biodiversity conservation and food production on the same land, using wildlife-friendly farming methods, as opposed to land sparing, i.e., spatially separating resource-producing and wildlife-producing land (e.g. Fischer et al., 2008). All habitat types considered in our study correspond to fully productive agricultural systems, without specific environmentally friendly management practices or natural habitats. However, our results suggest that spatial distribution of production systems providing different suitability values for species may also have a key role for conservation at a local scale. This has important management implications, since it suggests that whether changes should be made, their impact on some species (e.g. little bustards and calandra larks in our case study) can be minimized if they can be spatially distributed so that their impact can be minimized. Frameworks such as the one developed in this study could help to incorporate such issues at first stages of land use planning, so that policy and land use decisions have the opportunity to be coherent with both agronomic and conservation objectives.

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Table 1. Expected landscape-scale land use composition (% of total surface, by crop type) according to the three considered land use change scenarios and their sub-scenarios (NI = No Irrigation, PI = with Partial Irrigation). Current landscape composition is also shown.

	Current (%)	Business as usual (%)		Liberalization (%)		Local Markets (%)	
		NI	PI	NI	PI	NI	PI
Cereals	69	55	60	80	30	35	25
Fodder	7	0	0	5	5	0	0
Fallow land	4	0	0	0	0	0	0
Olive trees	7	20	20	5	20	25	30
Almond trees	12	5	0	5	15	10	10
Vineyard	0	5	5	5	20	20	20
Grain legumes	0	10	5	0	0	5	5
Oil seed crops	0	5	10	0	5	5	5
Fruit trees	1	0	0	0	5	0	0
Aromatic plants	0	0	0	0	0	0	5

Table 2. Resource-based habitat suitabilities for nesting and foraging for little bustard, calandra lark and stone curlew in different farming systems under rainfed conditions and partial irrigation.

	Little bustard		Calandra lark		Stone curlew	
	Nesting	Foraging	Nesting	Foraging	Nesting	Foraging
Dry conditions						
Cereals	0.63	0.51	0.39	0.54	0.19	0.34
Fodder	0.63	0.55	0.39	0.58	0.19	0.35
Fallow	0.36	0.93	0.85	0.93	0.64	0.57
Olive trees	0.00	0.38	0.00	0.00	0.50	0.63
Dry fruit trees	0.00	0.42	0.00	0.00	0.50	0.67
Vineyard	0.00	0.37	0.00	0.00	0.50	0.58
Grain legumes	0.50	1.00	1.00	1.00	0.50	0.64
Oil seed crops	0.45	0.54	0.13	0.56	0.25	0.50
Fruit trees	-	-	-	-	-	-
Aromatic plants	-	-	-	-	-	-
Partial irrigation						
Cereals	0.61	0.49	0.29	0.51	0.08	0.39
Fodder	0.61	0.46	0.29	0.48	0.08	0.39
Fallow	-	-	-	-	-	-
Olive trees	0.00	0.29	0.00	0.00	0.50	0.46
Dry fruit trees	0.00	0.42	0.00	0.00	0.50	0.79
Vineyard	0.00	0.50	0.00	0.00	0.50	0.88
Grain legumes	0.67	1.00	1.00	0.67	0.33	0.29
Oil seed crops	0.45	0.35	0.13	0.29	0.25	0.21
Fruit trees	0.00	0.42	0.00	0.00	0.50	0.79
Aromatic plants	0.60	0.56	0.80	0.40	0.40	0.27

Table 3. Model performance of resource-based habitat suitability models for predicting the occurrence of the three studied steppe bird species in the study area. Sample size (total number of presences plus absences/pseudo-absences, N), number of presences, AUC, sensitivity (percentage of correctly classified presences), specificity (percentage of correctly classified absences or pseudo-absences) and the threshold that maximizes the sum of sensitivity plus specificity are given.

Species	N	Presences	AUC	Threshold	Sensitivity (%)	Specificity (%)
Little bustard	34	17	0.77	0.52	0.88	0.47
Calandra lark	31	16	0.66	0.44	0.88	0.60
Stone curlew	35	17	0.70	0.30	0.59	0.78

FIGURE CAPTIONS

Figure 1. Overview of the framework followed for scenario development. Qualitative importance of different socio-economic drivers used to structure scenarios (a) is represented as very low (0), medium (+) or high (++).

Figure 2. Effects of land use changes associated with each scenario on the weighted averaged suitability indices (left) and percentage of suitable habitat (right) across the study area for little bustard, calandra lark and stone curlew. Scenarios and sub-scenarios: BU: business as usual, BU-I: business as usual with partial irrigation, L: liberalization, L-I: liberalization with partial irrigation, LM: development of local markets, LM-I: development of local markets with partial irrigation. In grey, scenarios with spatially non-aggregated land use changes and in white scenarios with spatially aggregated land use changes. Dashed lines indicate values for current landscape composition. For each scenario, mean value and standard deviation of 10 simulations are shown.

Figure 1.

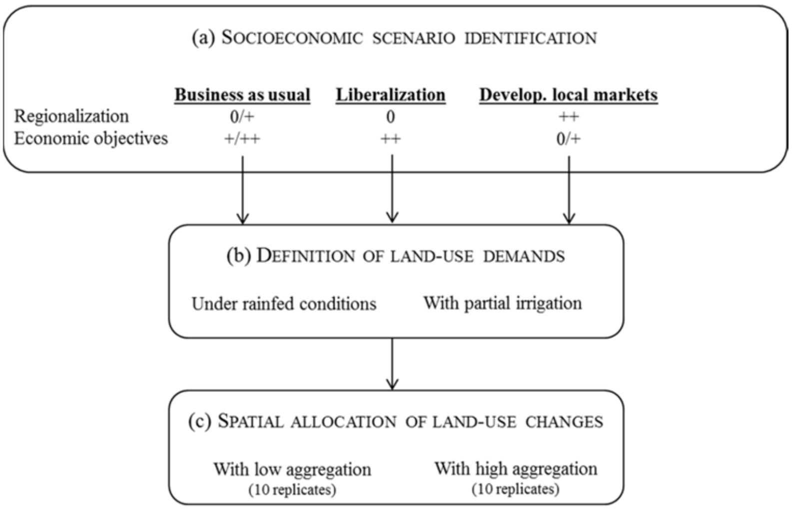
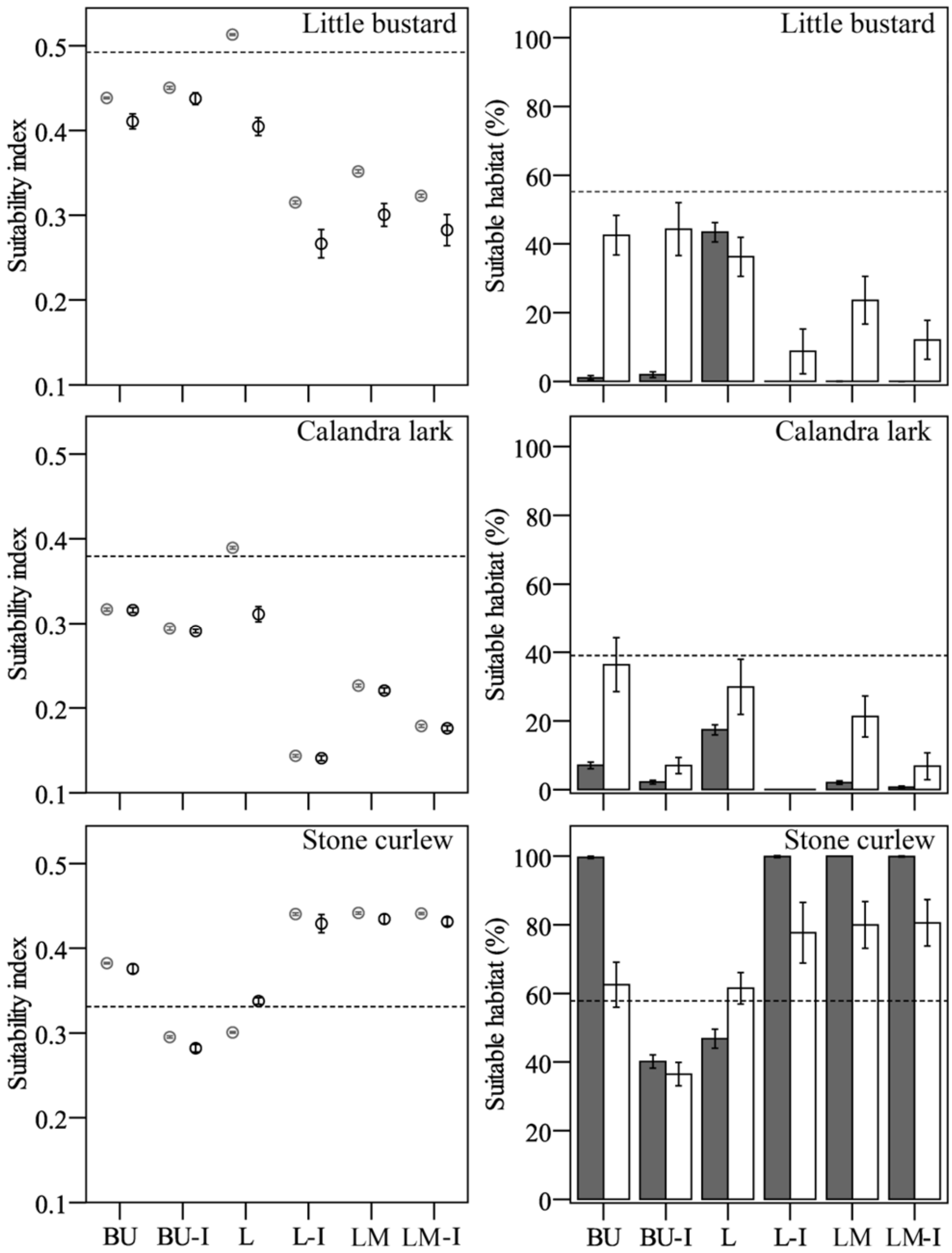

(a) Socioeconomic scenario identification
Business as usual
Liberalization
Develop. local markets
Regionalization
0/+
0
++
Economic objectives
+/++
++
0/+
(b) Definition of land-use demands
Under rainfed conditions
With partial irrigation
(c) Spatial allocation of land-use changes
With low aggregation
(10 replicates)
With high aggregation
(10 replicates)

Figure 2.



Little bustard
Suitability index
0.5
0.4
0.3
0.2
0.1
Little bustard
Suitable habitat (%)
100
80
60
40
20
0
Calandra lark
Suitability index
Calandra lark
Suitable habitat (%)
Stone curlew
Suitability index
Stone curlew
Suitable habitat (%)
BU
BU-I
L
L-I
LM
LM-I

Appendix A

Spatial allocation of land-use changes

We develop a demand-allocation procedure in R software version 3.0.2 to stochastically allocate the land-use demands associated with each scenario to polygonal spatial units while taking into account environmental constraints as well as different degrees of land-use spatial aggregation. This modeling approach updates an initial map of field units according to the scenario-dependent land-use demands and constrained by environmental conditions (specifically, terrain slope and soil salinity) in a single time step. To allocate the future demands on the current croplands, an iterative procedure is applied, and working as follows: first a target land-use type is selected proportionally to the land-use demands that remain to be allocated; then, for all the suitable field units, or where the target crop is cultivable according to the slope and the salinity rate characterizing each parcel, a probability (p_i) to change to that crop is assessed (see Eq.1); finally, a particular field is stochastically selected in relation to the set of individual probabilities p_i to change. These steps are repeated until the scenario-dependent demand per land-use category is reached.

The probability p_i of the field unit i to change to land-use type c is proportional to:

$$p_i \propto (1 - \sum_c I_{ic}) \cdot \sum_{j \neq i} I_{jc} e^{-\alpha |d_{ij}|} \qquad \text{(Eq.1)}$$

where I_{jc} is an identity descriptor with value 1 if the field unit j has already undergone change to the land-use type c and 0 otherwise, d_{ij} is the Euclidian distance between the field unit i and j,and α is a kernel exponent to set different degrees of land-use spatial aggregation. Note that p_i will be 0 if the field unit i has already changed to a future land-use type because I_{ic} will be 1 for c equal to that land-use type, avoiding field units to transform more than once within the time step

Appendix B

Resource-based habitat suitability estimates

We used a resource-based modelling approach to estimate habitat suitability for each species in a given land-use using a modified version of a resource-based modelling framework previously developed in the study area (Cardador et al., 2014). Resource-based modelling follows three steps: (1) the construction of a matrix to describe species' resource requirements (i.e. dietary, foraging habitat and nesting habitat) for each species and for each time period considered; (2) the quantification of resource availability in each habitat type and for each time period; (3) the calculation of habitat suitability indices for each of the vital activities for each species in each habitat type throughout the breeding season.

Step 1: Species' requirements

We built resource requirement matrices for diet, foraging and nesting habitat requirements during the breeding season for the study species by gathering bibliographic data from published papers and reports (Cardador et al., 2014). For foraging and nesting habitat description, four vegetation height categories (0-25 cm, 25-50 cm, 50-100 cm, >100 cm) were defined according to available information. For each category, we registered the capability of each species for using it as an ordinal measure (0 = not usable, 1 = usable). For diet we considered four main food types (seeds, plants, invertebrates and vertebrates) and registered the degree of preference for each of them by each study species (0 = not used, 0.5 = rarely used, 1= preferentially used (Cramp and Simmons, 1994)). Values were derived for two periods, spring (April-June) and summer (July-September), to reflect differences in resource requirements through the breeding season.

Step 2: Resource availability

We then characterized resource availability in each possible farming system in the study area through the breeding season in terms of species habitat requirements (i.e. vegetation height and food supply). On the one hand, we used available information on agricultural practices applied to different farming systems in our study area (Cantero and Moncunill, 2012) in combination with authors' expert knowledge based on 10 years of field surveys, to qualitatively describe the probability (0 not possible, 0.5 rare or infrequent and 1 usual) that a given farming system presents a given vegetation height (i.e., 0-25 cm, 25-50 cm, 50-100 cm, >100 cm) in each month of the breeding season. For orchard crops, vegetation height of herbaceous strata was described. We then transformed these values to relative frequencies by dividing the score of each category by the sum of scores of all categories in a given period and land cover type, so that the sum of all categories was 1 (Table B1).

For diet, we estimated expected abundance of the four considered food types according to agricultural practices applied (Cantero and Moncunill, 2012). We assumed that the relative abundance (*ab*) of a particular food type in a given farming system was inversely related to the number of agricultural practices (*n*) that negatively affect that resource. Specifically we use the equation $ab = 1 / (n + 1)$, where $n + 1$ was used in order to avoid infinite values. For these calculations, we considered the effect of five main practices that are known to be related to food abundance: fertilizers use, herbicide use, irrigation, plough and weed cut (Table B2). These practices can lead to reduction in food supply of our study species directly (e.g. reduction in weed availability through the use of herbicides) or indirectly (e.g. elimination through competition of many broad-leaved plant species and invertebrates associated with them by stimulation of crop growth through crop irrigation or fertilizer use) (Benton et al., 2002; Newton, 2004). Expected food abundance was calculated for spring (April-June) and summer (July-September).

Step 3: Resource-based habitat suitability calculations for the whole breeding season

For each species and farming system considered, we calculated suitability values for nesting habitat structure (S^{NH}), foraging habitat structure (S^{FH}) and diet (S^{FD}) as $\Sigma\, a_i \cdot r_i \cdot t$, where a_i is the relative frequency of each vegetation height category i in S^{NH} and S^{FH}, and expected abundance of food type i in S^{FD}; r_i is the capability (i.e., 0 or 1) of the species for using vegetation height category i in S^{NH} and S^{FH} calculations, and the degree of preference (i.e., 0, 0.5, 1) for food resource i in S^{FD} calculations; t is a modifier describing the tolerance to orchard crops of each species, t is set to 0 for S^{NH} and S^{FH} calculations of orchard crops for species that avoid them and to 0.5 for species with intermediate levels of tolerance, t is set to 1 in all other cases. All calculations were conducted monthly, according to the temporal resolution of vegetation height data. However, we assumed that (1) food preferences remained constant across both spring (April-June) and summer (July-September) periods and (2) availability of food was constant within each period but potentially varied between them.

In our framework, foraging habitat suitability depends on both habitat characteristics and availability of food resources (Catry et al., 2012; Wilson et al., 2005). Thus, we calculated final foraging habitat suitability estimates as $S^F = \sum_t S_t^{FH} \cdot S_t^{FD}$, where *t* are the months of the breeding season. In contrast, nesting habitat suitability in a given habitat is defined as the suitability derived from nesting habitat characteristics only. Thus, we calculated it as $S^N = \sum_t S_t^{NH}$, where *t* is the duration of the nesting period (number of months).

Table B1. Vegetation structure throughout the breeding season of different possible farming systems in the study area. Usual (dark color), infrequent (light color) and not possible (white) vegetation height categories are shown. Numbers indicate relative frequencies (%) of different vegetation height categories in each farming system and month.

Farming system	Month	Vegetation height (cm)[2]			
		0-25	25-50	50-100	>100
Dry cereal / fodder	Apr	0	75	25	0
Dry cereal / fodder	May	0	25	50	25
Dry cereal / fodder	Jun	25	0	50	25
Dry cereal / fodder	Jul	50	0	25	25
Dry cereal / fodder	Aug	100	0	0	0
Dry cereal / fodder	Sep	100	0	0	0
Irrigated cereal / fodder	Apr	0	75	25	0
Irrigated cereal / fodder	May	0	20	40	40
Irrigated cereal / fodder	Jun	0	0	50	50
Irrigated cereal / fodder	Jul	33	0	33	33
Irrigated cereal / fodder	Aug	100	0	0	0
Irrigated cereal / fodder	Sep	100	0	0	0
Dry / irrigated oil seed crops	Apr	0	40	40	20
Dry / irrigated oil seed crops	May	0	0	50	50
Dry / irrigated oil seed crops	Jun	0	0	50	50
Dry / irrigated oil seed crops	Jul	100	0	0	0
Dry / irrigated oil seed crops	Aug	100	0	0	0
Dry / irrigated oil seed crops	Sep	100	0	0	0
Dry grain legumes	Apr	33	67	0	0
Dry grain legumes	May	33	67	0	0
Dry grain legumes	Jun	33	67	0	0
Dry grain legumes	Jul	100	0	0	0
Dry grain legumes	Aug	100	0	0	0
Dry grain legumes	Sep	100	0	0	0

Farming system	Month	Vegetation height (cm)[2]			
		0-25	25-50	50-100	>100
Irrigated grain legumes	Apr	25	75	0	0
Irrigated grain legumes	May	25	75	0	0
Irrigated grain legumes	Jun	25	75	0	0
Irrigated grain legumes	Jul	25	75	0	0
Irrigated grain legumes	Aug	25	75	0	0
Irrigated grain legumes	Sep	25	75	0	0
Irrigated aromatic plants	Apr	40	40	20	
Irrigated aromatic plants	May	40	40	20	
Irrigated aromatic plants	Jun	40	40	20	
Irrigated aromatic plants	Jul	40	40	20	
Irrigated aromatic plants	Aug	40	40	20	
Irrigated aromatic plants	Sep	40	40	20	
Dry / irrigated orchards[1]	Apr	100			
Dry / irrigated orchards[1]	May	100			
Dry / irrigated orchards[1]	Jun	100			
Dry / irrigated orchards[1]	Jul	100			
Dry / irrigated orchards[1]	Aug	100			
Dry / irrigated orchards[1]	Sep	100			

[1]Orchards includes: olive trees, almond trees, vineyard and sweet-fruit trees

[2]Relative frequencies were calculated by assigning a numeric value to each descriptive value (i.e., not possible = 0, infrequent = 0.5, usual = 1) and

dividing the score of each category by the sum of scores of all categories in a given period and land cover type, so that the sum of all categories was 1

Table B2. Main agricultural practices applied to possible farming systems in the study area in spring (Sp) and summer (Su). Practices likely to influence study steppe bird food resources (seeds, plants, invertebrates and vertebrates) in each farming systems (ticks) and those with no effect (crosses) are shown. Practices considered included fertilizer use, herbicide use, irrigation, plough and weed cut.

Farming system	Agricultural practices					Food availability*			
	Fert[1]	Herb[1]	Irrig[1]	Plough[2]	Cut[2]	Seeds	Plants	Invertebrates	Vertebrates
Dry cereal / fodder (Sp)	**V**	**V**				0.33	0.33	0.33	1
Dry cereal / fodder (Su)				**V**		0.5	0.5	0.5	0.5
Irrigated cereal / fodder (Sp)	**V**	**V**	**V**			0.25	0.25	0.25	1
Irrigated cereal / fodder (Su)				**V**		0.5	0.5	0.5	0.5
Dry oil seed crops (Sp)	**V**	**V**				0.33	0.33	0.33	1
Dry oil seed crops (Su)						1	1	1	1
Irrigated oil seed crops (Sp)	**V**	**V**	**V**			0.25	0.25	0.25	1
Irrigated oil seed crops (Su)						1	1	1	1
Dry grain legumes[3] (Sp)	**V**	**V**				0.33	1	0.33	1
Dry grain legumes[3] (Su)						1	1	1	1
Irrigated grain legumes[3] (Sp)	**V**	**V**	**V**			0.25	1	0.25	1
Irrigated grain legumes[3] (Su)						1	1	1	1
Irrigated aromatic plants (Sp)	**V**		**V**	**V**		0.25	0.25	0.25	0.5
Irrigated aromatic plants (Su)			**V**	**V**		0.33	0.33	0.33	0.5
Dry olive trees (Sp)	**x**	**V**		**V**		0.33	0.33	0.33	0.5
Dry olive trees (Su)						1	1	1	1
Dry dry-fruit trees (Sp)	**x**	**V**		**V**		0.33	0.33	0.33	0.5
Dry dry-fruit trees (Su)						1	1	1	1
Dry vineyard (Sp)	**x**			**V**		0.5	0.5	0.5	0.5
Dry vineyard (Su)						1	1	1	1
Irrigated olive trees (Sp)	**x**	**V**	**x**		**V**	0.33	0.33	0.33	1
Irrigated olive trees (Su)						1	1	1	1
Irrigated dry-fruit trees (Sp)	**x**	**V**	**x**		**V**	0.33	0.33	0.33	0.5
Irrigated dry-fruit trees (Su)						1	1	1	1
Irrigated vineyard (Sp)	**x**		**x**	**V**		0.5	0.5	0.5	0.5
Irrigated vineyard (Su)						1	1	1	1
Irrigated fruit trees (Sp)	**x**	**V**		**V**	**V**	0.25	0.25	0.25	0.33
Irrigated fruit trees (Su)		**V**	**x**		**V**	0.33	0.33	0.33	0.5

*Food availability of each food resource was calculated as 1 / (n + 1), where n is the number of agricultural practices that negatively affect food resource considered.

[1] Practices likely to influence seeds, plants and invertebrates.

[2] Practices likely to influence seeds, plants, invertebrates and vertebrates.

[3] In the case of grain legumes, negative effects of agricultural practices were only considered to affect seeds, invertebrates and vertebrates, but not plant material since the crop by itself could be consumed by plant-eaters.

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Figure A1. Predicted land use and habitat suitability maps for little bustard, calandra lark and stone curlew in the study area according to different land use change scenarios with low spatial aggregation of land use changes. Scenarios and sub-scenarios: BU: business as usual, BU-I: business as usual with partial irrigation, L: liberalization, L-I: liberalization with partial irrigation, LM: development of local markets, LM-I: development of local markets with partial irrigation. Maps shown for each scenario are based on 1 model simulation. Current landscape composition and habitat suitability values are also shown.

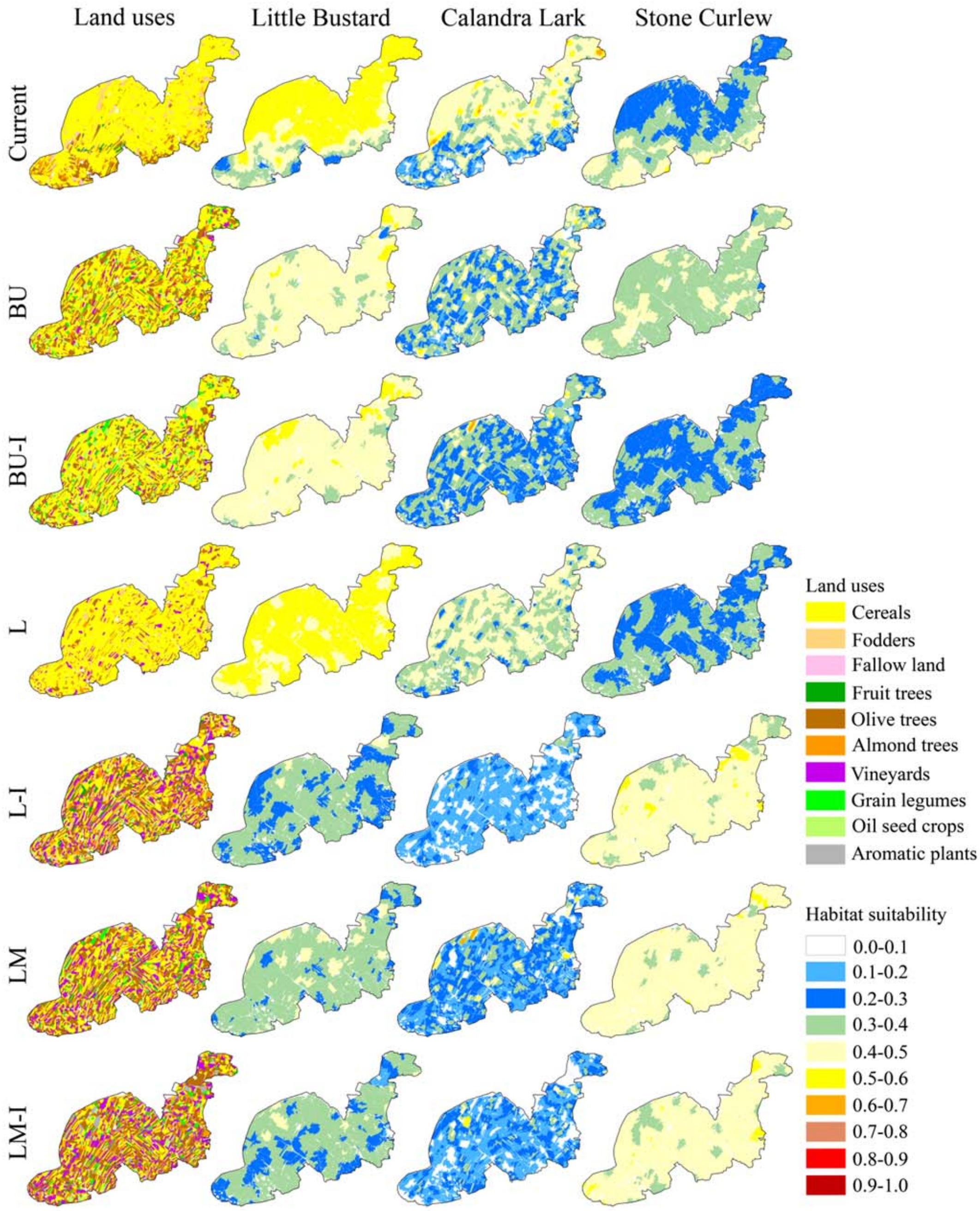

Figure A2. Predicted land use and habitat suitability maps for little bustard, calandra lark and stone curlew in the study area according to different land use change scenarios with high spatial aggregation of land use changes. Scenarios and sub-scenarios: BU: business as usual, BU-I: business as usual with partial irrigation, L: liberalization, L-I: liberalization with partial irrigation, LM: development of local markets, LM-I: development of local markets with partial irrigation. Maps shown for each scenario are based on 1 model simulation.